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PERCEPTION OF MOTION ORIENTATION USING DIVERGENCE, SIZE CHANGE --ETC(U)

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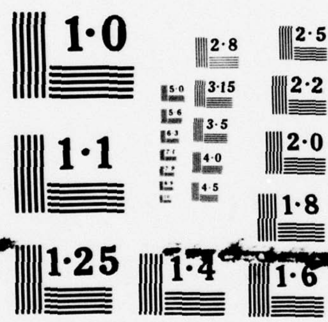

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Report 1978-5

PERCEPTION OF MOTION ORIENTATION USING DIVERGENCE, SIZE CHANGE AND VELOCITY CHANGE

Thomas L. Harrington and Marcia K. Harrington

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Department of Psychology
University of Nevada, Reno
Reno, NV 89557

August 1978

Technical Report for Period 1 January 1977 - June 1978

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As an observer moves relative to a textured surface such as the ground there is motion-related visual information available from that surface through three specific geometrical variables. These are vergence, size change and velocity change. As the textural elements move closer to the observer their paths of motion on the retina diverge. Movement away leads to convergence. Size of the elements also changes as function of distance as does velocity. The purpose of this experiment was to determine the effectiveness of each

(continued)

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variable and to assess their interactions in foveal and in peripheral viewing. The objective was to acquire information needed for movement display design as well as to discover more about the information humans use for orientation.

In this experiment displays were viewed in which the three variables were electronically separated and variously presented singly, in all possible pairs, and altogether in one display. The oscilloscope display consisted of 64 downward moving elements designed to simulate a moving surface tilted 75° away from the observer. Subjects communicated their perceptions of degree of perceived surface tilt at the top, bottom and middle of the display for the eight different combinations of variables. They also responded to apparent velocities of these same display areas.

The results showed that all three variables can lead to relatively reliable perceptions of motion in depth with velocity change being the most powerful determiner and with size change being the weakest. Subjects consistently underestimated the amount of simulated tilt.

Foveal viewing was more accurate than peripheral viewing but peripheral performance nevertheless was found adequately consistent to function as an input channel in many orientation tasks.

Certain combinations of the variables led to perceptions of extreme warping and should be avoided in motion displays.

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INTRODUCTION

Whenever there is relative movement between an observer and his textured surroundings the optical information available to him takes on three new aspects; each is related to the type of motion. These three motion-related variables are tied together under ordinary circumstances. The purpose of this experiment is to untie them and assess their respective contributions to the perception of three-dimensional motion in two-dimensional displays.

The first of these variables is divergence. When a textured surface moves closer the textural elements spread apart, thus the trajectories of their images on the retina diverge. For example, when a pilot flies his craft over a landing field the pebbles in the surface below seem to move apart as they approach in divergent trajectories. If the motion is fast enough blur patterns will be formed that consist of diverging blur lines. This topic has been covered in previous reports (Harrington and Harrington, 1977; Harrington and Harrington, 1978).

Tied to divergence, in fact produced by it in a sense is the second variable, size change. As the distance between textures and an observer lessens, the size of the retinal images of textural elements becomes larger as does the apparent size.

The third variable is velocity change. It includes acceleration and all of the higher motion derivatives. As an object nears on any but a collision course its retinal image's velocity becomes faster and faster as does the apparent transverse velocity under normal conditions. For instance, highway signs seem to have zero transverse velocity at great distance but appear to move very rapidly as they are passed.

The present study employed a computerized oscilloscope display to present these three variables in all of their possible combinations as each would be seen if the elements were moving on a particular surface, tilted a fixed amount in depth. The object was to determine their contributions and interactions to the perception of three-dimensional motion. This procedure was carried out stimulating each of five retinal areas. Figures 1 through 8 show each of the possible display conditions.

Initially the dependent variable was to be orientation of a paddle about a horizontal axis. It was thought that as each variable was added to the display of 64 downward-

streaming elements more and more apparent tilt might be produced so that each variable's contribution to perceived orientation could be found from how the subject oriented his paddle when he was asked to match the slant of the simulated surface; however, for certain combinations of variables severe distortions were perceived in the synthetic surface. It appeared that bent or elastic transformations became evident wherein the surface seemed to stretch. Therefore it was necessary to ask subjects to match the simulated surface's orientation at the top, at the bottom and in the middle to obtain a measure of the bending. Also to assess the perception of stretch, magnitude estimates of the velocity were taken at the top, bottom and center of the display.

Specifically, 6,000 data points were collected from five subjects in a 3x8x5 factorial design whose respective factors were screen area responded to, stimulus type or condition and fixation point or retinal area stimulated.

The actual questions to be answered were: 1) Do the separate variables of divergence, size change and velocity change contribute to the perception of motion in the third dimension when presented alone, in pairs and altogether? 2) When and how do these variables interact to produce bending or stretching or both? 3) Can any of these variables be dispensed with when simulating three-dimensional motion in two dimensions--for example, in the case of a moving surface? 4) What are the relative effects of these three varaibles in the foveal field and in different parts of the peripheral visual field?

DESCRIPTION OF THE EXPERIMENT

Subjects

Five subjects, all students of the University of Nevada, Reno were paid for their participation. Three women and two men served as subjects in the present investigation. All had normal visual acuity.

Procedure

Each subject completed six sessions with each session being approximately one hour in duration.

The initial session was used to familiarize the subjects with the equipment and the two kinds of tasks to be performed: (1) adjusting a plastic "paddle" (located on a table in front of the subject) to correspond with the perceived slope of the visual display; (2) giving a velocity estimate for the moving

visual pattern. All subjects were seated in the viewing booth 29 inches from the 5-inch diameter oscilloscope screen and viewed the screen through a 1" diameter circle (to control for head position). Subjects were asked to fixate on one of five viewing points, the importance of remaining fixed on the specified spot and viewing the screen out of the corner or bottom of the eye was stressed. The subjects' eyes were monitored to ensure appropriate fixation. After fixating at the specified point, the subjects viewed the display of moving elements and used the paddle to indicate what they perceived to be the slope of the surface along which the elements were moving (and this was done separately for the top, middle, and bottom sections of the screen--with the order of the sections varying randomly from trial to trial). After setting the paddle, the subjects gave a number representing how fast the elements were moving along the slope in that section. The stimulus duration was six seconds and there was an interval of two seconds between stimulus displays.

Experimental Design

The simulated orientation (the visual display of moving elements) which was presented to the subjects on the oscilloscope screen had three variables: divergence, element size change, and velocity gradient. All possible combinations of these variables were used, so that there were eight different patterns or conditions presented to the subjects, ranging from a display in which the elements diverged, changed size and had a velocity gradient (condition 1) to a control condition which was a moving display with none of these variables (condition 8). The other conditions included: (2) divergence, size change; (2) divergence, velocity gradient; (4) velocity gradient, size change; (5) velocity gradient; (6) divergence; (7) size change. Each subject had five trials (with three paddle settings per trial--top, middle, bottom) for each condition at each of the five fixation points (central, 20° above; 40° above; 40° left; 80° left), thus making a total of 200 trials per subject.

In the Results section paddle settings only will be discussed. The results of the velocity estimation will be presented at a later time.

Equipment and Stimulus Generation

There were eight stimulus conditions representing all configurations of the presence or absence of the three stimulus variables of velocity change, divergence and size change. When velocity change was required, the vertical digital-analog converter output was processed such that the desired 75° slant simulation was achieved (Figure 9). But the x- input to the oscilloscope was unprocessed. Otherwise

the vertical merely provided its normal 0-255 sawtooth function to provide a linear vertical sweep. When both velocity change and divergence were required, both the x- and the y-signals were processed in accordance with the equation. When only divergence was required an amount of the y-signal was multiplied with the x-signal to produce a new set of x-values that increased in distance about the center vertical path as the y-signal grew. The amount of the divergence was the amount that should be present if the subject were actually viewing elements moving on a surface tilted 75 degrees from vertical away from him.

The sizes of the elements were similarly changed. The elements were circular in shape and were produced by feeding a sine wave to the y-axis and its phase-shifted counterpart, a cosine wave to the x-axis. In conditions where size change was required, an amount of the vertical or y-signal was multiplied with the sine wave generator output using a balanced modulator configuration to give both the final sine and the final cosine components sizes that were properly dependent upon the momentary vertical signal. Thus, whether the y-signal was going through the perspective transformation or not, circle size could either be constant or could change as it should if the subject were actually viewing elements moving on a surface tilted away by 75 degrees.

Switches controlling whether each of the variables was present or absent were ganged so that conditions were selectable by an eight- position rotary switch set prior to each trial by the experimenter. Intertrial interval and stimulus duration were controlled by the computer.

RESULTS

An analysis of variance showed that the variables of subject, stimulus condition, session and fixation were significant far beyond the .01 level. The stimulus condition by fixation and the condition by block by fixation interactions were also highly significant. Screen area viewed was not significant (Figure 10); however, a large screen area effect is noted for condition VS with the top of the screen being judged more slanted than the middle and the middle more slanted than the bottom.

Figure 11 showing the paddle settings for each display condition indicates this effect.

The control condition, C, in which no depth information was present, corresponds to a paddle setting of nearly 90 degrees or vertical. Then as size changes (S), divergence

(D), divergence and size (DS), velocity change from the top of the screen to the bottom (V) and velocity and divergence (VD) and finally velocity, divergence and size change (VDS) are added the perceived tilt of surface increases to a maximum of about 55 degrees from vertical for the VD condition. The fact that VDS was not more effective still was not anticipated; this is discussed in the next section.

Figure 12 shows the data for the fixations presented separately. The letters a, b, c, d and e signify subject fixation foveally, 20 degrees above the target, 40 degrees above, 40 degrees left and 80 degrees left respectively. No clear relationship between fixation and condition emerges; however, in Figure 13 it is evident that as fixation becomes more central there is a slight but significant tendency for more motion in the third dimension to be seen.

Orthogonal comparisons showed that the separate conditions all differed significantly from the control condition indicating each variable by itself and in combination with the others was effective in providing three-dimensional motion information.

DISCUSSION

Display Variables

At the outset of the experiment it was not clear how each single variable or each combination of variables might effect the perception of motion in depth. It might have been true for instance, that isolating size change or velocity change led to the perception of perhaps a surface that seemed tilted in depth to the degree of the simulation's intent, or it might have been that the impression was one of no tilt, it might have been that a lateral stretching was seen as the elements changed size, or it might have been that velocity change led to an apparent vertical stretching or to accurate perception of the surface orientation or to an impression of elements that actually changed velocity rather than growing nearer either on a tilted surface or on a perpendicular one. Similarly, with divergence of the paths of the elements, it could have been that divergence of trajectories gave a fairly accurate perception of slant as diverging lines do in a perspective drawing, or it might have been that the divergence was not projected into the third dimension at all but was seen simply as divergence in a vertical pattern, or lateral stretching could have been produced or pure divergence in the absence of size change and/or velocity change could have led to varied warping or bending of the surface on which the

elements seemed to move. Finally, any of the three variables could have failed to produce any depth and the way in which they combined could have been linear or non-linear.

Phenomenally, introduction of any of the variables into the control pattern created some impression of depth as the data verifies. When only element size was changed, a sort of looming was present. The elements seemed to approach as they became larger on the way down the screen. The impression of a surface was softened slightly by the fact that the elements did not change shape as naturally-occurring elements do and thus appeared to remain vertical in spite of their apparent forward motion.

When only divergence was present, the subjective impression was one of the appropriate motion in depth, but not entirely compelling, rather more suggestive since the elements remained the same size and the velocity down the screen was constant.

When only velocity was present, the impression was subjectively somewhat different than the paddle-setting data would indicate. Since no divergence nor size change was present the elements moved down parallel paths without changing size. The appearance was one of a group of raindrops or similar objects that started slowly and accelerated. If a surface was imagined, then this acceleration gave rise to a marked perceptual stretching of the surface as the elements moved down. If only the acceleration were appreciated then the elements seemed to be under the influence of some accelerating force. There seemed to be very little resemblance to gravitational acceleration because the motion function just "looked" wrong. Also one seemed to miss the divergence that would accompany a field of elements possessing such a large change in velocity (which would imply a large distance being covered in the gravitational field). Also, with velocity only, a characteristic of waterfalls was seen. The slowly-moving elements at the top seemed to have a little more motion toward the observer than the faster-moving elements farther down the screen; thus the impression was like watching leaves approach a waterfall and then descend. This effect is not evident in the paddle-setting data, perhaps because the breakover seemed to occur more toward the top of the display than the subjects had been instructed to regard for their "top" paddle settings.

When velocity and size were present without divergence the waterfall effect was again seen but the stretching was perceptually contaminated by the looming effect due to size change and, as was the case in some of the other conditions in some areas of the screen, an impossible-figure feeling

was had by the viewer and either ambiguous or alternating perceptions were experienced. From the data though it appears that the subjects sensed depth because in this condition, more than any of the others, they gave significantly disparate paddle settings for the top, middle and bottom of the viewing screen as Figure 11 clearly illustrates.

According to the data, when velocity and divergence are present and size change is not, oddly enough, the maximum effect of third-dimensional motion is found even though when viewing the velocity-divergence-size change pattern the impression of motion in depth toward the observer is more striking. It is suspected that the lack of shape change (circles on a highway for example would become less and less elliptic as they approached) may have contaminated the impression of actual motion on a surface since the circles did not appear to lie down properly. When they had constant size their size was smaller than the larger circles when size change was present (size was then the average of the smallest and the largest when size change was present). In pilot research with circles whose shapes did change in various ways, shape change was found to be an extremely potent variable in terms of shaping perception of the situation, namely whether one was seeing a flat surface, a three-dimensional array of "floating" elements, etc.

During the construction and testing of the pattern generator an additional feature, a sort of by-product of the design, led to the possibility of testing the various influences and interactions of the three variables, and of shape change as well, in a different way than the method used in these experiments. This is noted here in passing because of the potential of the method and because it produced some startling visual impressions. The technique is one of pitting one variable against another. For example, if velocity were to be small at the top of the screen and increase toward the bottom as though the surface containing the moving elements were tilted away from the observer (as in the case of an airport runway) and at the same time if the elements started out large at the top of the screen and got smaller and smaller toward the bottom as they would if the surface were tilted toward the observer (as in the case of a ceiling), the question would be which variable would win out. Also, would it be possible to mix different amounts of one variable to cancel out the effects of another and produce a resultant surface with no tilt in either direction from the perpendicular? Then the relative strengths of the variables could be measured as they each influenced perception of slant.

It was also possible to put the vanishing point, usually at the top of the pattern on the horizon, in the middle of the figure so that it appeared as a runway and a ceiling meeting at the horizon with selected combinations of variables having a normal relationship on one of the surfaces and an opposing relationship on the other. Then often the depth perception would fail completely in one sense and emerge in another. In one case the "horizon" lost its impression of distance and the top and bottom corners of the figure took on depth to give the impression of a figure rotating in depth or, in another case, of a figure like a helical section with elements streaming down it.

Even though it was found that the three display variables under study were each significant contributors to perception of three dimensional motion in the two-dimensional display as measured by the paddle settings, and even though the paddle settings were very consistent from condition to condition, the judged amount of tilt was highly inaccurate. The subjects underestimated the simulated amount of tilt away from the vertical. The simulated surface was designed to represent a tilt away from the vertical of 75 degrees but the subjects only tilted the paddle on the average about 20 degrees from the vertical. Other investigators have noticed similar underestimation of slant (Braunstein, 1976). Researchers on the project agreed that the patterns could easily be interpreted as having a 75 degree tilt when the more compelling variable combinations were present. This dissimilarity between observers was probably not due to practice because over the five experimental sessions subjects failed to show any monotonic improvement. It is suspected that perceptual motivation may be involved and that the difference between subjects and professionals may reflect some attitudinal factors such as the difference between directly perceiving slant and cognitively inferring its existence from the stimulus parameters. It may also be that subjects lack the perceptual sophistication necessary to "see" a three dimensional entity while "knowing" that only two dimensions are involved. Further research on this question is important to this type of visual simulation.

Locus of Retinal Stimulation

Whether different regions of the retina were differentially sensitive to the combinations of the three motion-related variables is important to simulation problems, especially when the display must share the visual system's attention with other tasks requiring foveal vision. If motion orientation from the three variables under study here were good in the periphery compared to the fovea, then

certain motion displays could be situated in the peripheral field, freeing the fovea for tasks like instrument reading that require fine spatial discrimination.

According to the results shown in Figure 13 such is the case under these experimental conditions. While the fovea does see significantly more depth than an extreme peripheral location like 80 degrees left, as Figure 12 shows, where the foveal viewing designated by the 'a's on the graph does provide perception of slightly more tilt as more tilt-related variables are added, still in terms of the overall error the amount of foveal versus peripheral disagreement is negligible.

It was expected that foveal viewing might far surpass peripheral viewing in accuracy because some of the cues such as size change require fine spatial discrimination even though in some motion-related visual processing peripheral vision is superior. Also it was thought that fixating above the screen might enhance accuracy because in normal viewing situations movement of the ground is seen on the upper retinal areas.

The results based on the specific fixations used show that neither of these contentions is true and that such displays can not only be processed in the periphery, the actual peripheral location is not particularly important, especially if the peripheral extremes are avoided.

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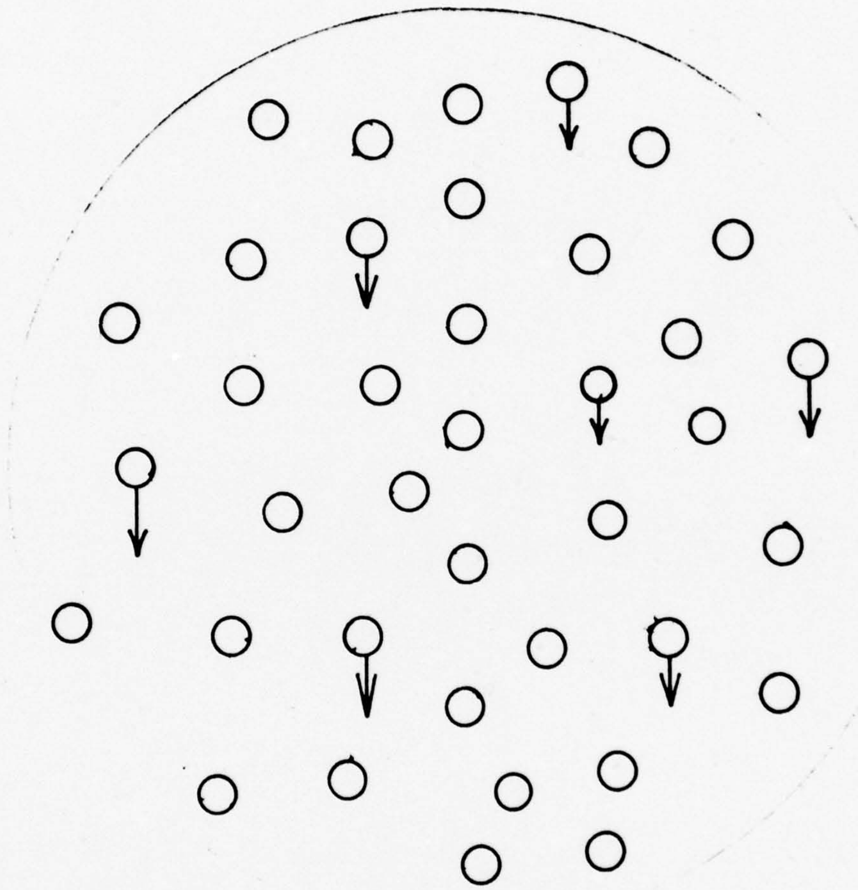


FIGURE 1

Control condition with velocity change, divergence and size change all held to zero.

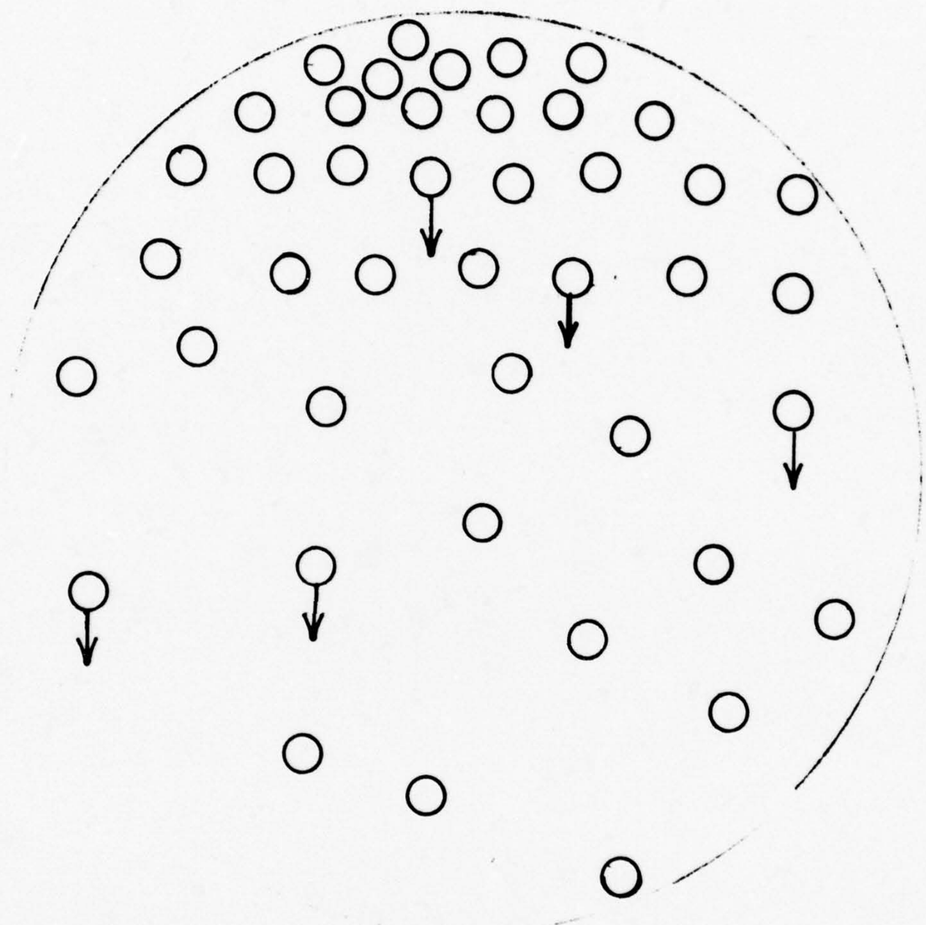


FIGURE 2

Display showing velocity change only with divergence and size change held to zero.

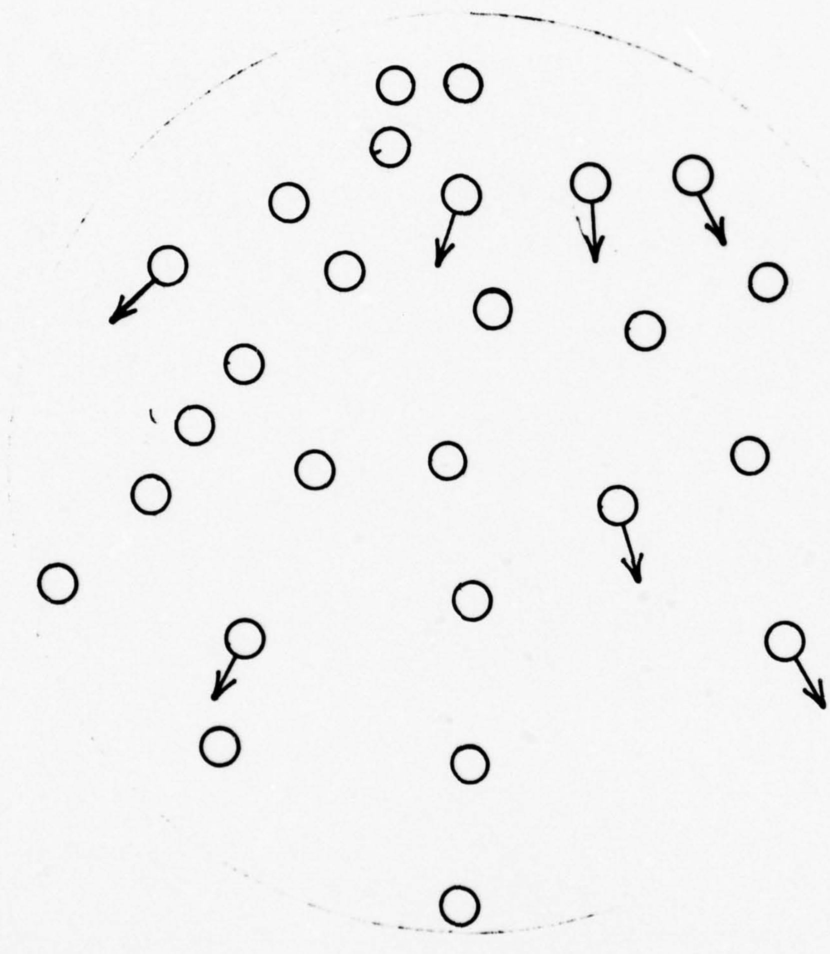


FIGURE 3

Display showing divergence only.

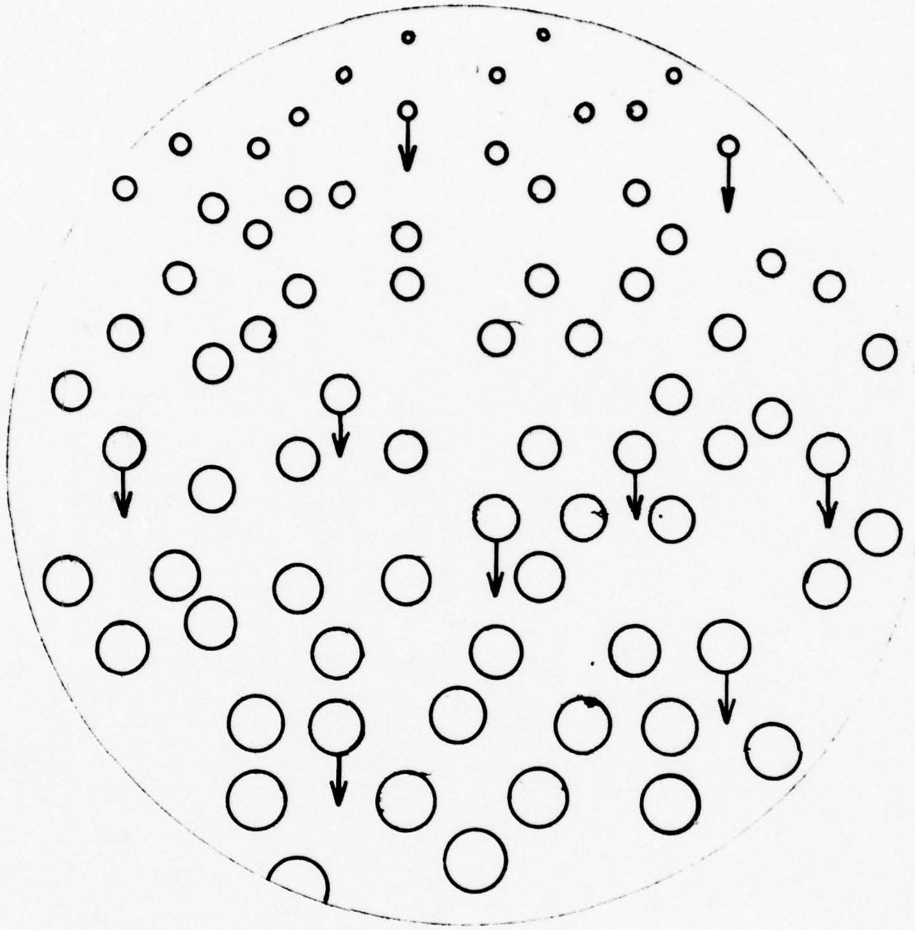


FIGURE 4

Display showing size change only.

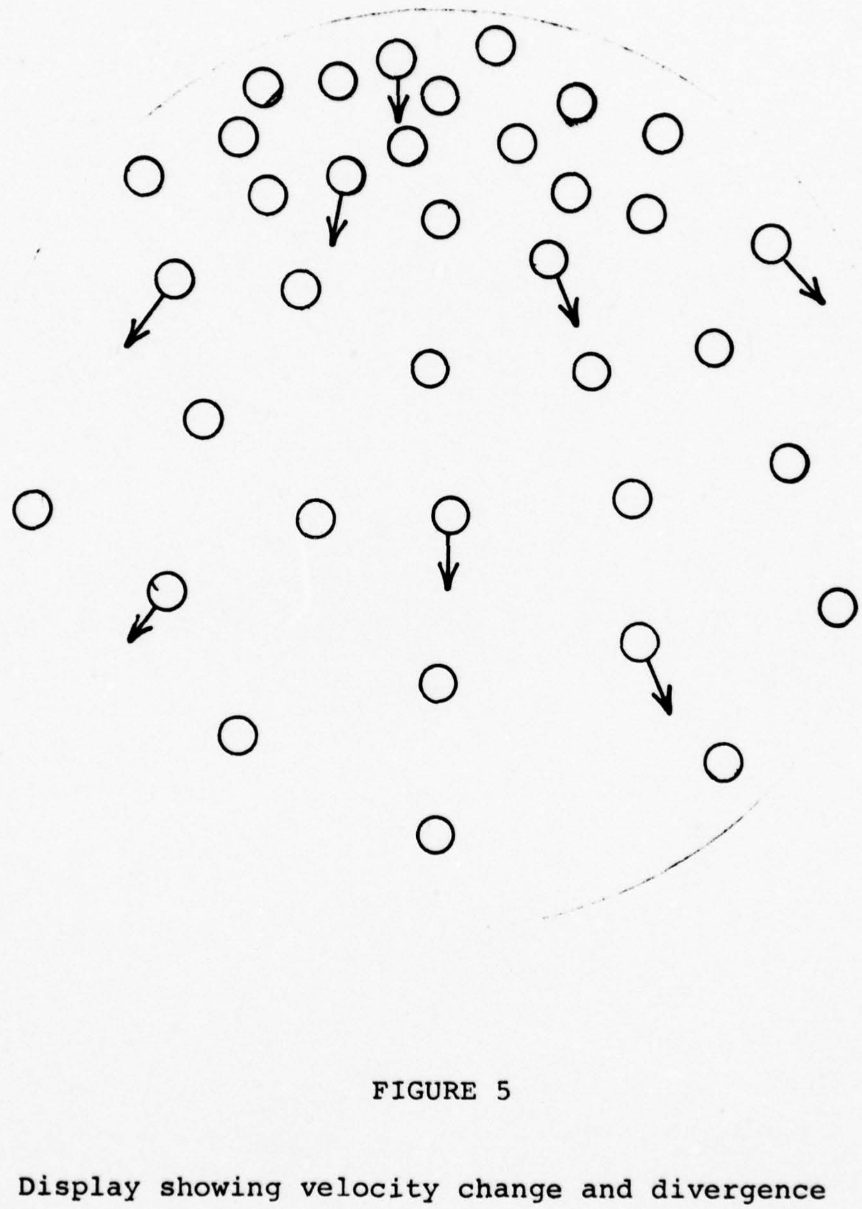


FIGURE 5

Display showing velocity change and divergence

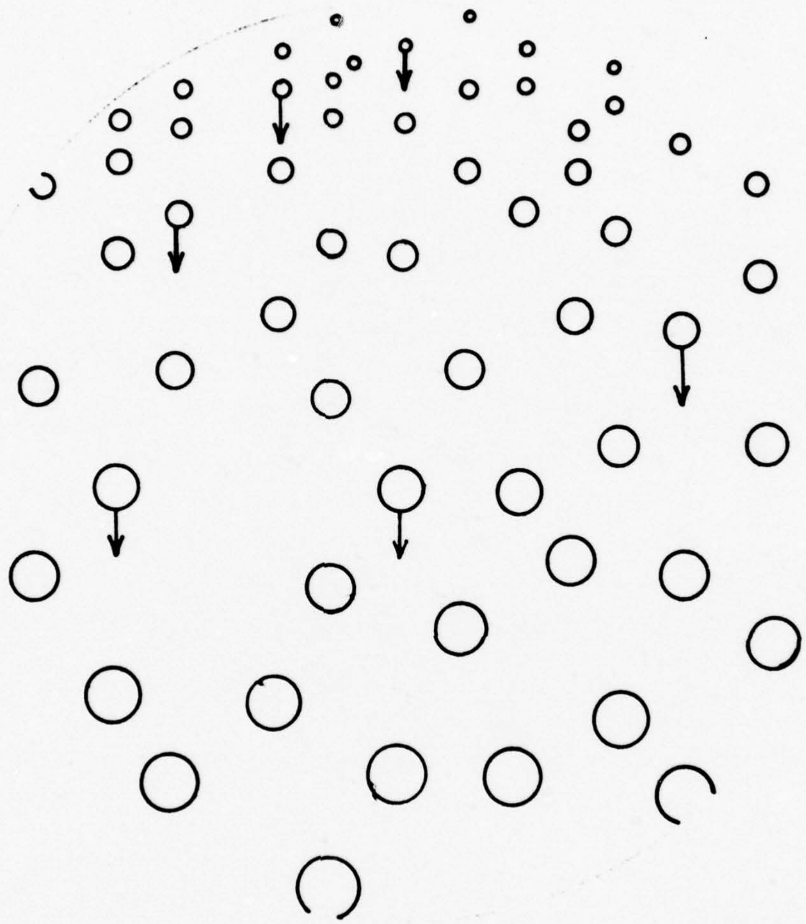


FIGURE 6

Display showing velocity change and size change.

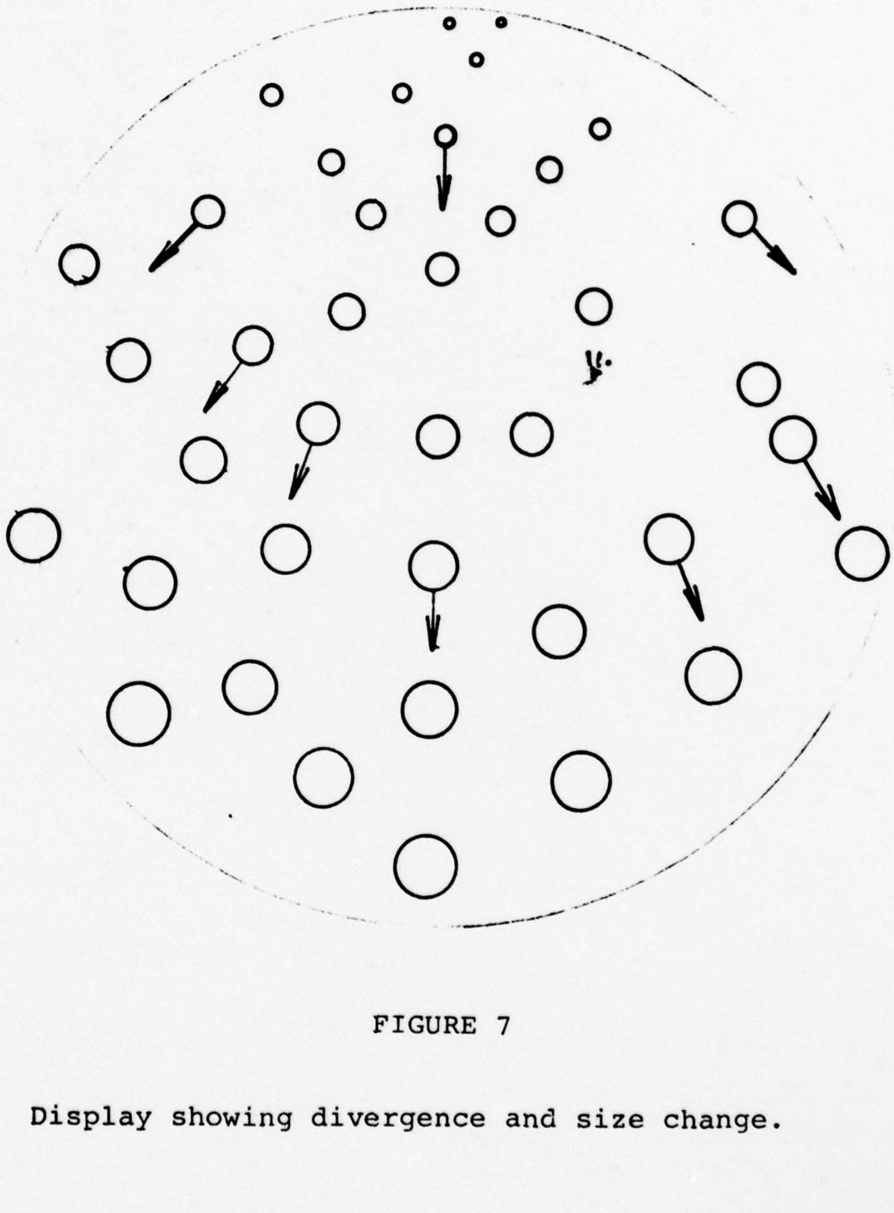


FIGURE 7

Display showing divergence and size change.

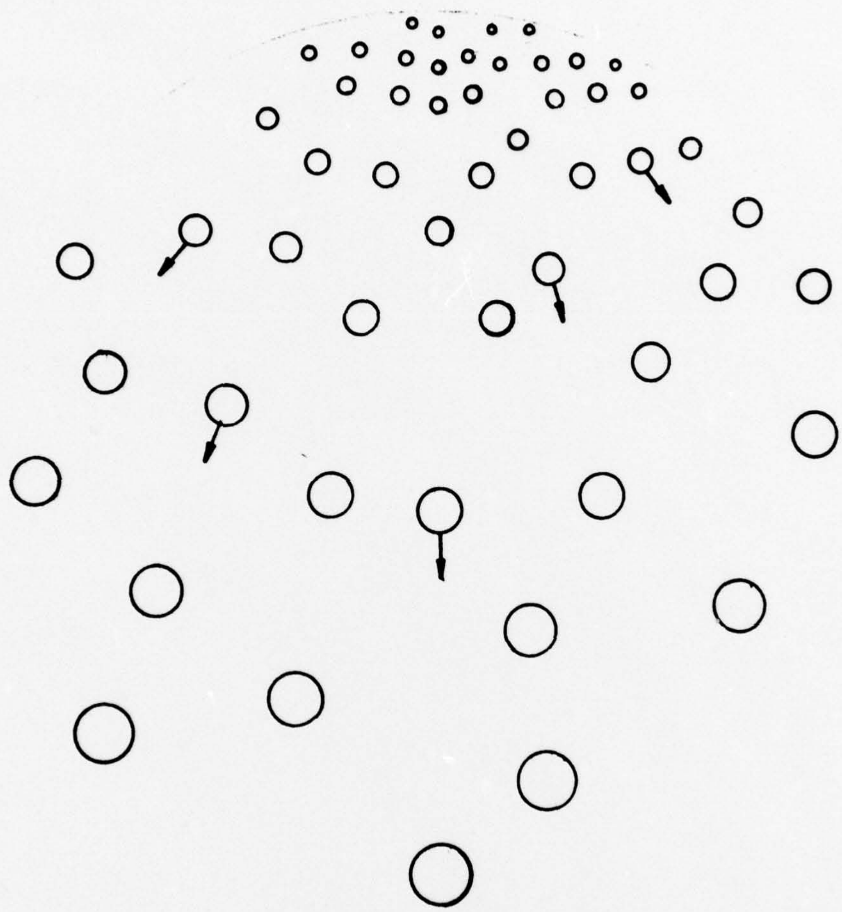


FIGURE 8

Display showing velocity change, divergence and size change all varying together.

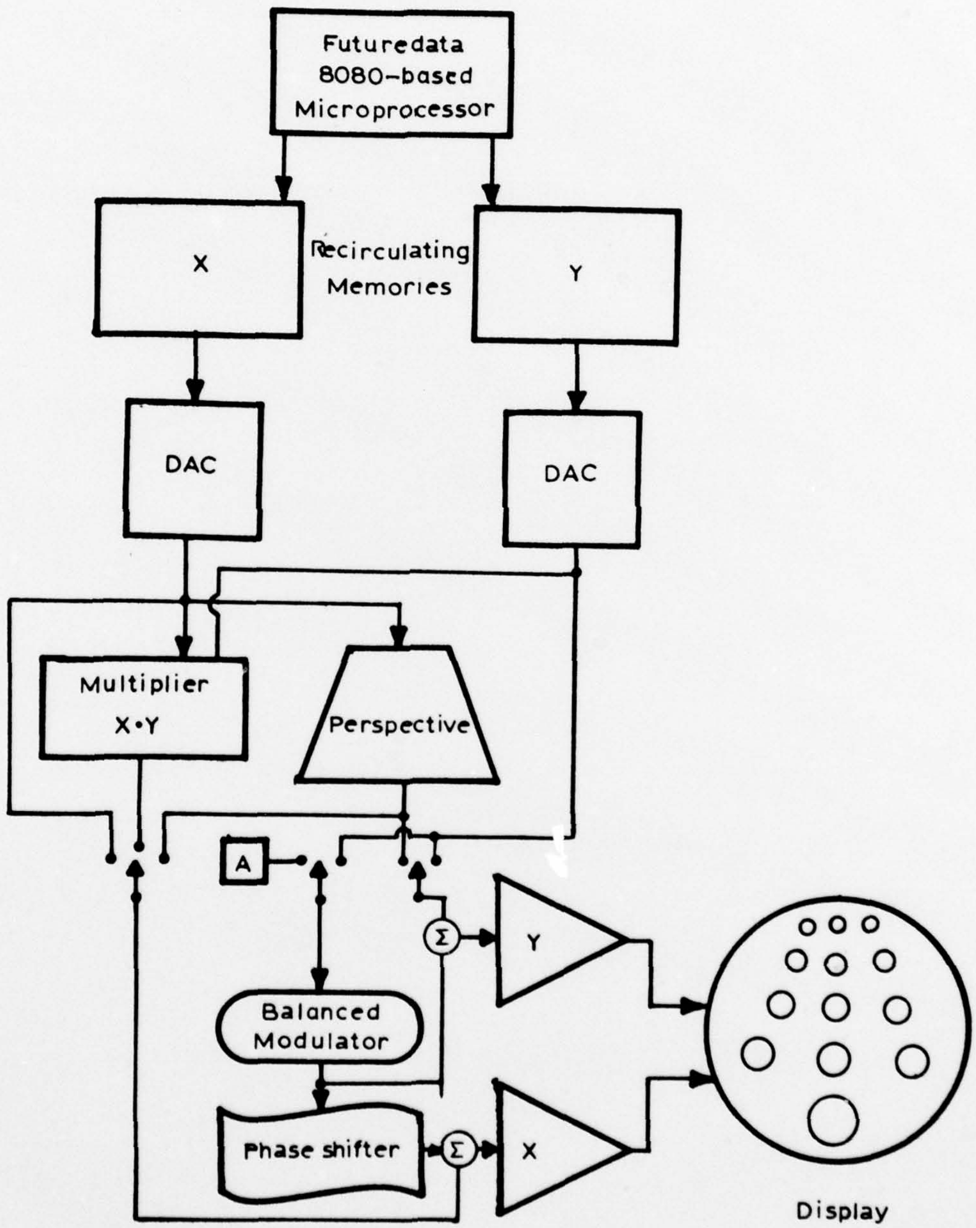


FIGURE 9

Schematic of equipment used to produce patterns whose size change, velocity size and divergence can be varied independently.

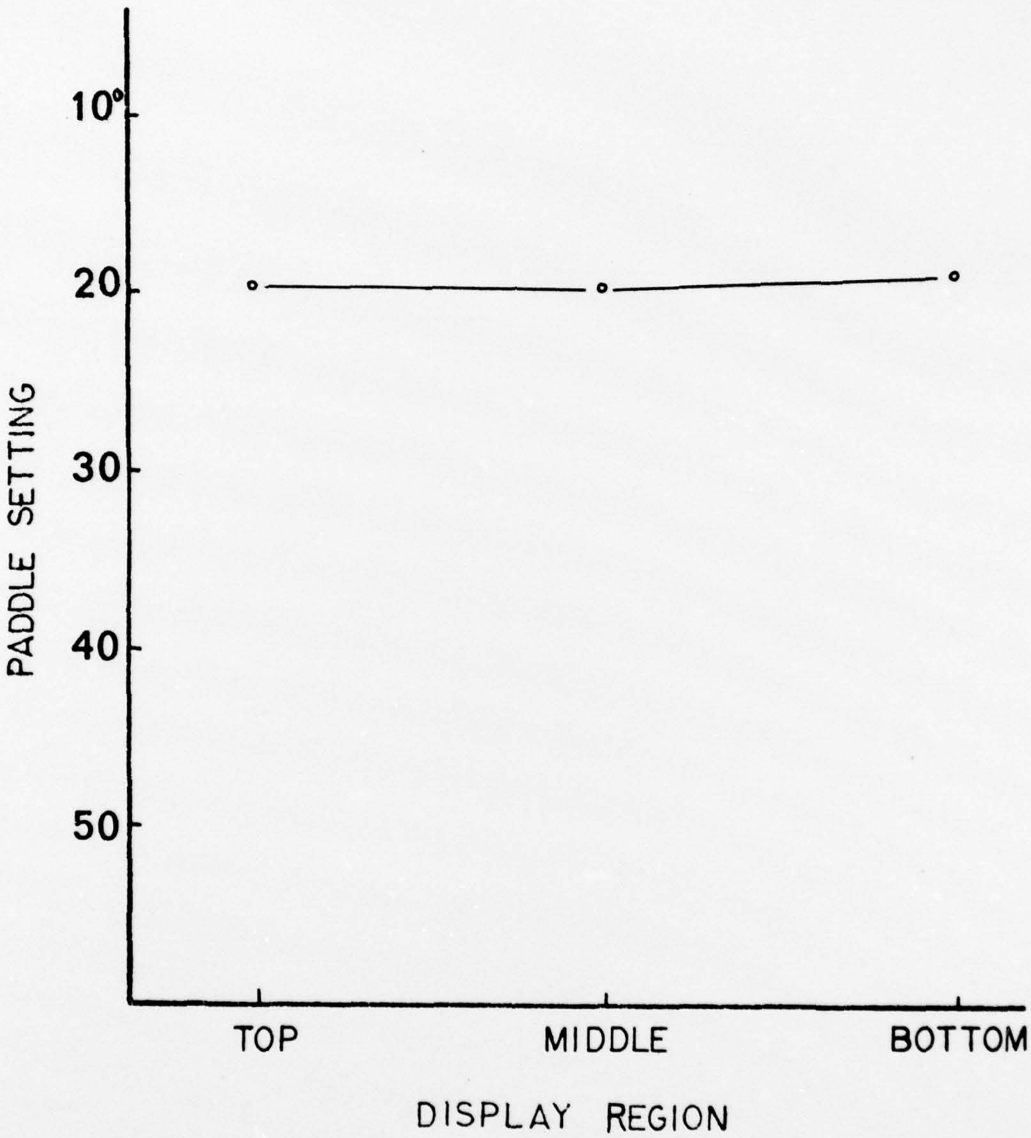
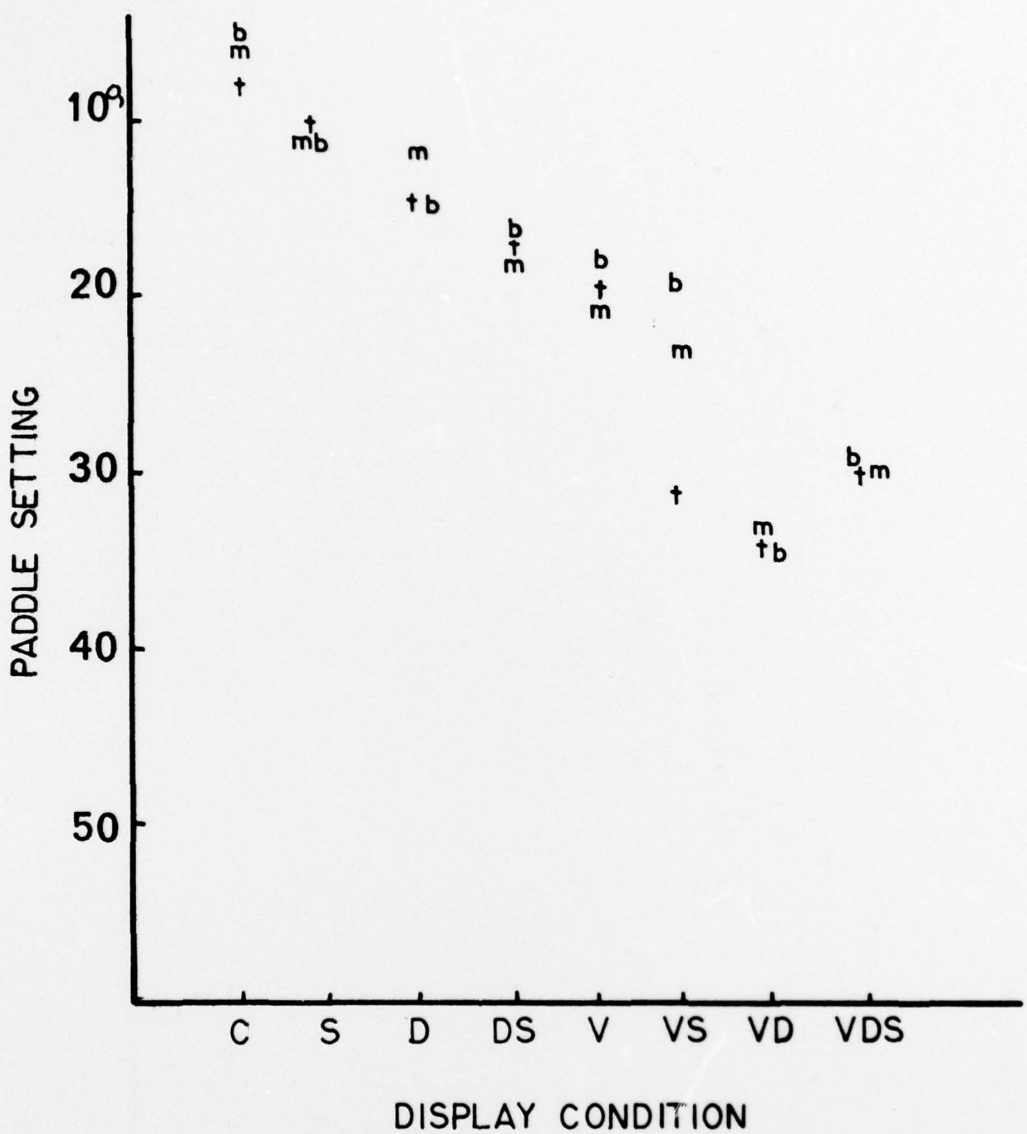

10°
20
30
40
50
PADDLE SETTING
TOP
MIDDLE
BOTTOM
DISPLAY REGION

FIGURE 10



PADDLE SETTING
10
20
30
40
50
C
S
D
DS
V
VS
VD
VDS
DISPLAY CONDITION

FIGURE 11

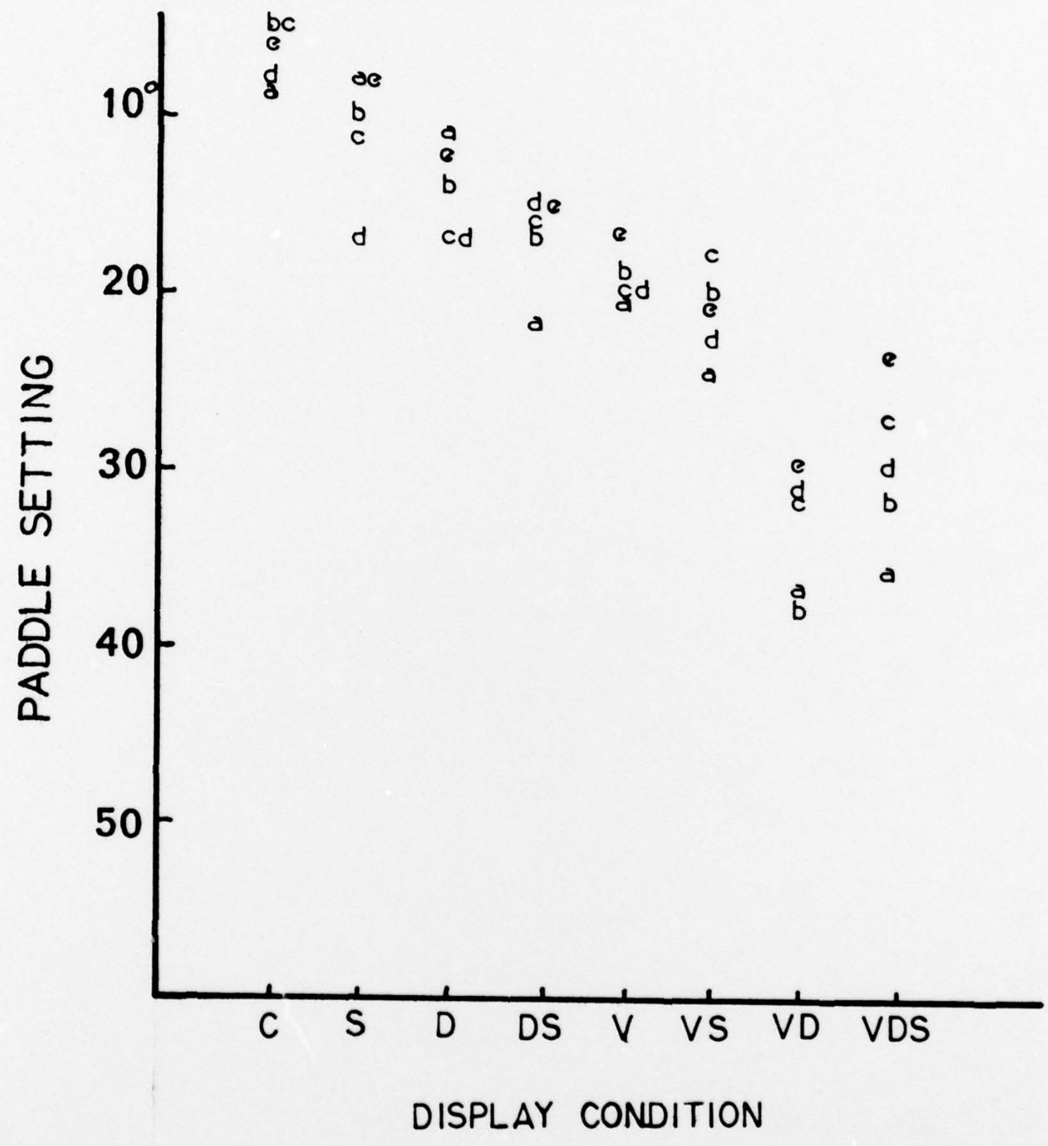

PADDLE SETTING
10°
20
30
40
50
C
S
D
DS
V
VS
VD
VDS
DISPLAY CONDITION

FIGURE 12

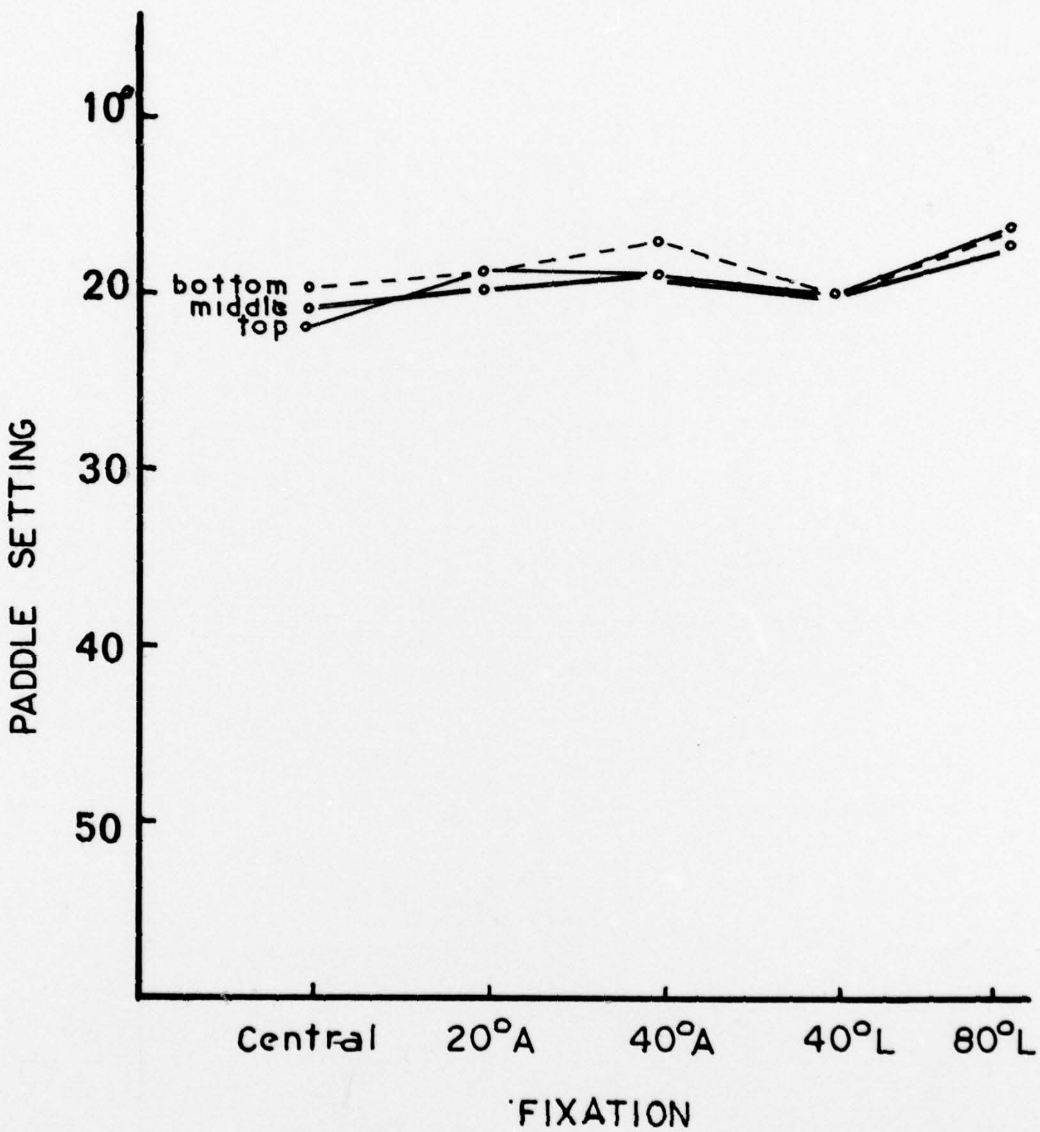

10°
20
30
40
50
PADDLE SETTING
bottom
middle
top
Central
20°A
40°A
40°L
80°L
FIXATION

FIGURE 13

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